ATLAS prospects for boosted objects.

On behalf of the ATLAS collaboration

Elin Bergeaas Kuutmann
DESY, Zeuthen

Outline

- The ATLAS detector
- Boost?
- Simulation studies of physics scenarios
  - jets in SUSY decays
  - hadronic decays of *W* / *Z*
  - *H* –> *bb*
  - top quarks
- A quick look at first LHC data
- From simulation to a boosted data object
- Summary and outlook

The ATLAS detector at the LHC

- General-purpose detector at the LHC
- Prepared for high p_T objects:
  - The inner detector has a high granulatrity for pattern recognition and is designed for excellent momentum resolution, primary and secondary vertex measurement.
  - The calorimeters cover $|\eta|<4.9$.
    EM calo thickness 22-24 X_0,
    11 λ in thickness at $\eta = 0$.
  - Calibration to the hadronic level of calorimeter energy clusters (*local calibration*) allows jet substructure studies

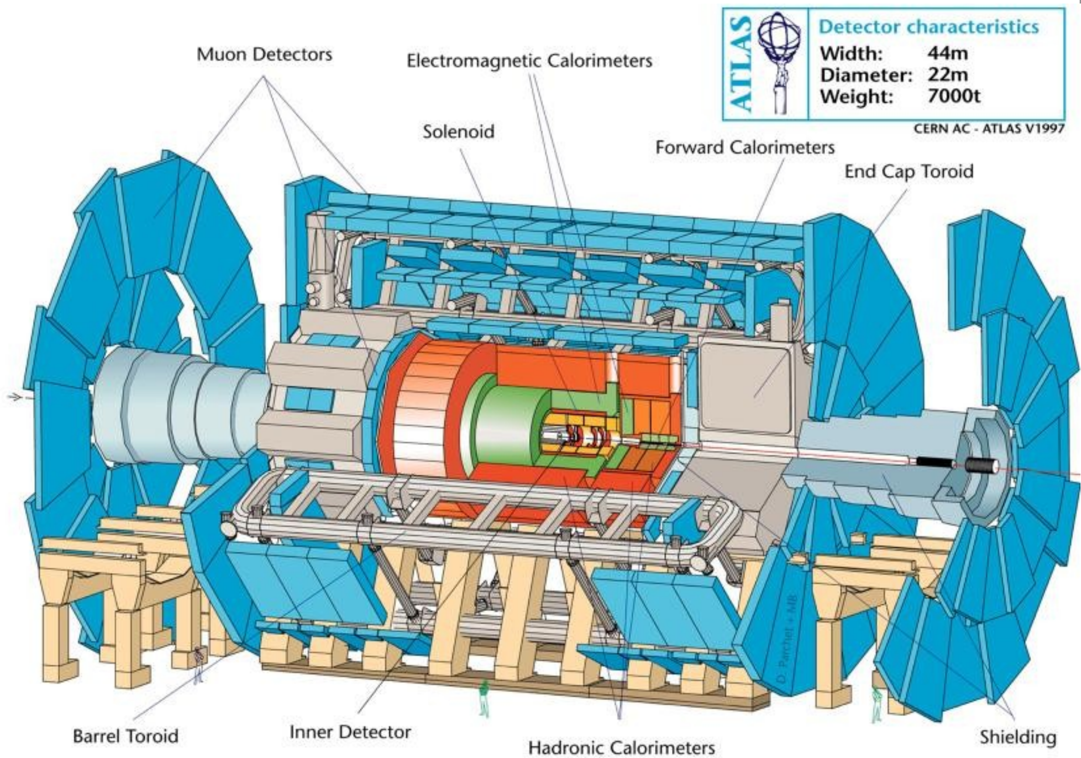
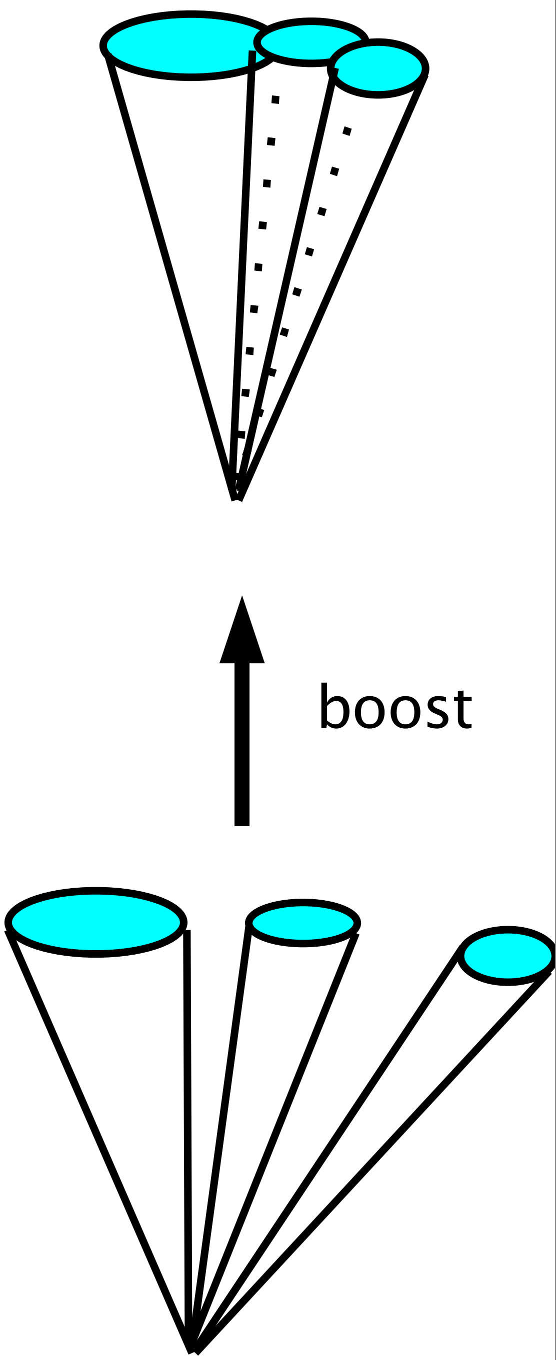


Image: CERN

Boost?

- Kinematically: a particle is boosted if it is relativistic
- Experimentally: we are concerned with boosted particles when the boost cause the standard algorithms to fail due to merged decay products, displaced vertices, etc.
- This talk follows the experimental approach: little about underlying models and more about reconstructing the actual objects



Jet searches

- The challenge: when heavy and/or boosted objects decay hadronically, the decay products may overlap and form a single, merged jet
  Investigated cases:
  - SUSY scenarios involving hadronic final states
  - $W \to q\,q'$, $Z \to q\,\bar{q}$
  - $H \to b\,\bar{b}$
  - ... etc.
- Common features: the jet substructure is investigated in order to suppress light QCD background
- The k_T, anti-k_T or Cambridge/Aachen jet algorithms used
- The FastJet package for accessing algorithms Phys.Lett.B641:57-61,2006

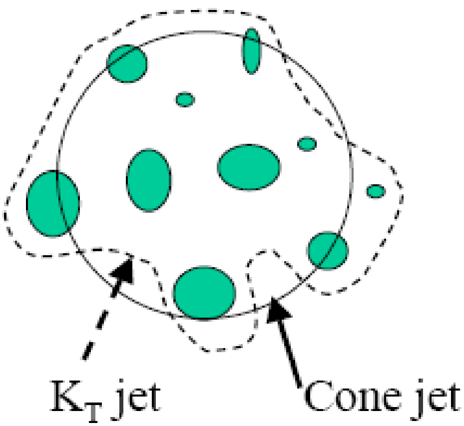
Jet searches: the k_T algorithm

Start with a list of calorimeter components (clusters, towers...)

1) For each component, define $d_i = p_{T,i}^2$

For each pair (i, j) define $d_{ij} = \min(p_{T,i}^2, \; p_{T,j}^2)\, \Delta R_{ij}^2 / R^2$

where $\Delta R_{ij}^2 = (\phi_i - \phi_j)^2 + (\eta_i - \eta_j)^2$



2) Find d_{min} = minimum of all d_i, d_{ij}

3) If d_{min} is a d_{ij}, merge clusters to a new cluster d_n

If d_{min} is a d_i, the object is a jet. Remove component i from list.

Repeat 1–3 until all components are in jets.

Note: – The last jets to form are the most energetic.

– The last and second-to-last d_{ij} values before forming a full jet carry information about the jet substructure.

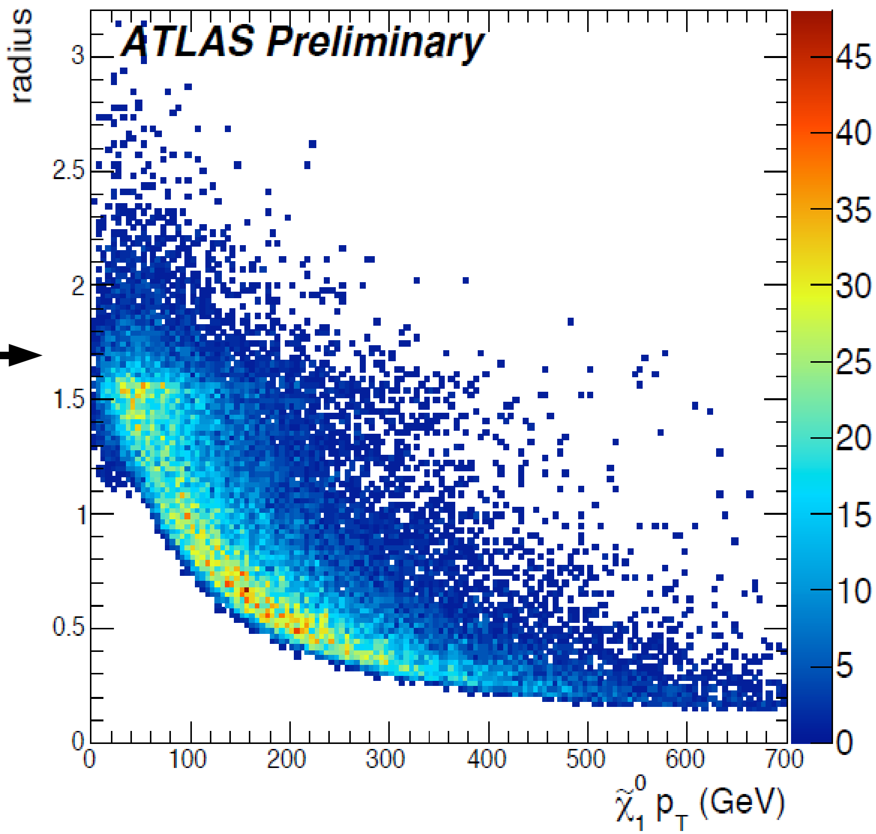
– The algorithm can be used “backwards” on any jet to obtain substructure information.

Boosted subjet searches in SUSY scenarios

(ATL-PHYS-PUB-2009-076)

Model: SPS1a with *R*–parity violating coupling $\lambda''_{112} \neq 0$ added to the Lagrangian => baryon number violating neutralino decay: $\tilde{\chi}_1^0 \rightarrow qqq$ m_χ=96.1 GeV and σ_{LO}=17.2 pb at 14 TeV.

- 3 quarks => 3 collimated jets, merging when the χ^0 p_T increases



- Event selection:
  - ≥4 jets, $|\eta|<2.5$ for the 4 leading jets
  - 2 jets with p_T>275 GeV
  - $y_2 > -0.17\, y_1 + 0.08$ for both these jets*)
  - 2 (other) jets with p_T>135 GeV

*) Define y_1 (y_2) as $y_n = d_{ij} / m$ where d_{ij} is the k_T splitting level from the last (second to last) merging, and *m* is the jet mass.

radius: a measure of the ΔR size of the 3-jet system

Boosted subjet searches in SUSY scenarios (2)

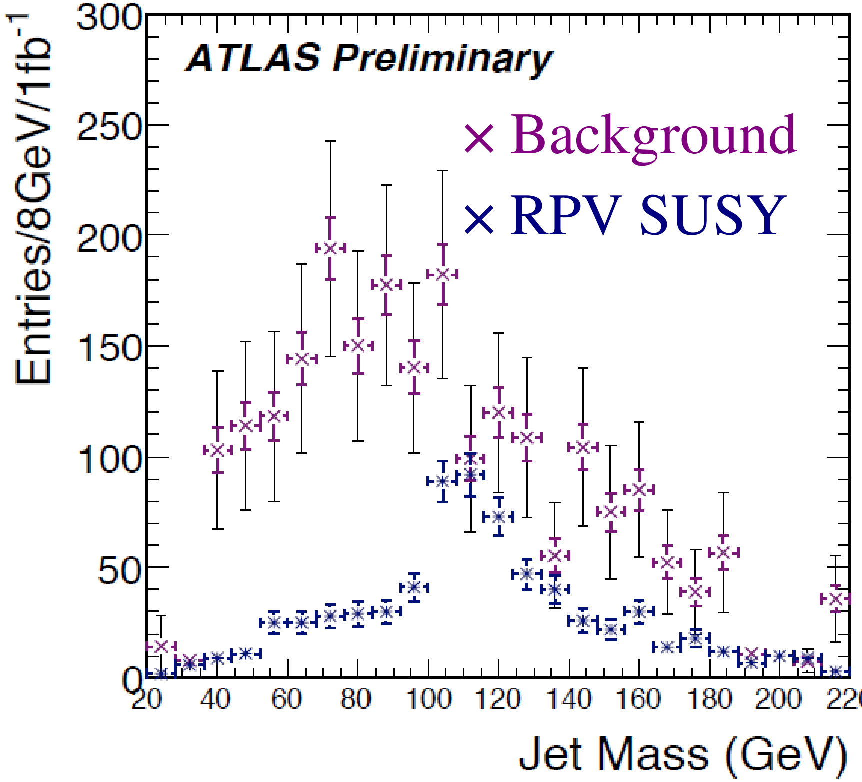
(ATL-PHYS-PUB-2009-076)

- Accumulative offline cut flow (events per 1 fb^{-1})

	≥4 jets, $|\eta|<2.5$	2 jets $p_T>275$ GeV	2 jets $y_2 > -0.17\, y_1 + 0.08$	2 (other) jets with $p_T>135$ GeV
SUSY	14577	5849	792	347
ttbar	2.3×10^5	2000	200	1
dijets	3.2×10^9	1.1×10^6	1.8×10^4	1100

- Triggers investigated: various jet triggers, multijet triggers and total jet energy triggers. High (>99%) efficiency after event selection.

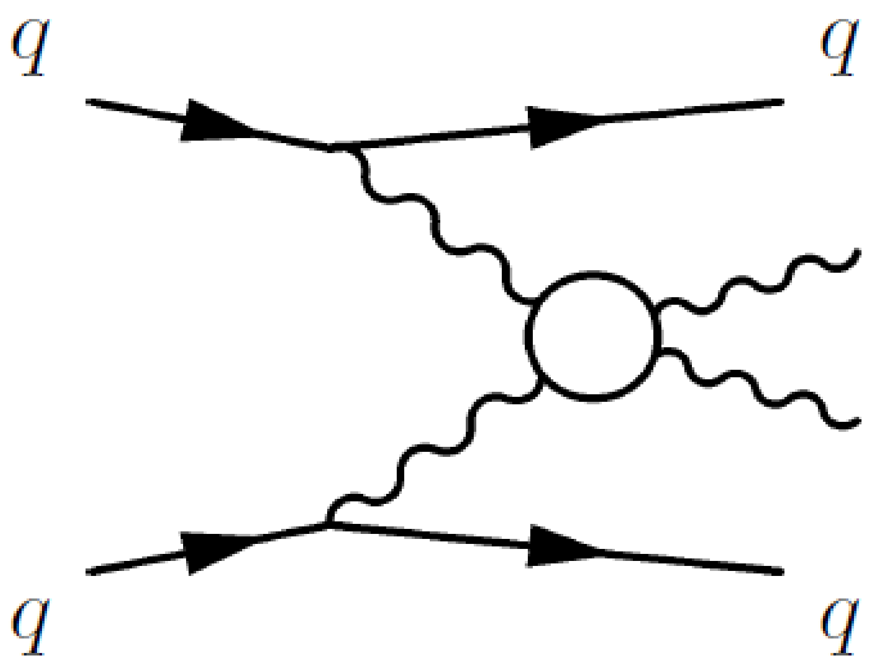
- **Result:** light jets background significantly reduced.
  This reconstruction method works for all pair production mechanisms of hadronic resonances (2 leading jets) with a decay chain (following jets)



Vector boson scattering

(CERN-OPEN-2008-020)

- In the absence of a light Higgs, several models exist that predict vector boson resonances.
- Here: Chiral Lagrangian model, in which a scalar or a vector resonance decays to two vector bosons
- Reconstruction of semileptonic decays
  - *V*-> *ll*. Standard recon-struction
  - *V*-> *qq*. Quarks are boosted from *V* mass => can be merged



Vector boson scattering (2)

(CERN-OPEN-2008-020)

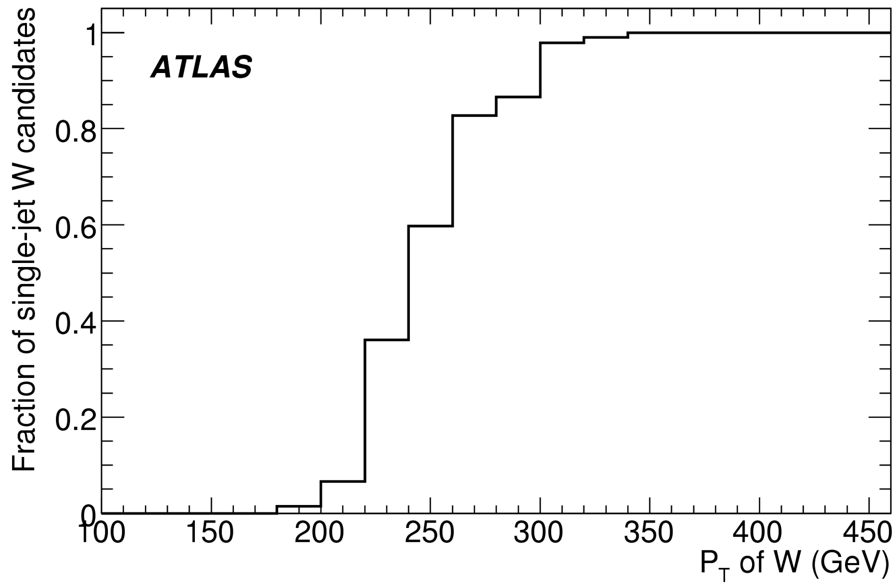
Finding the hadronic vector boson:

- k_T algorithm, R=0.6 on locally calibrated calorimeter clusters
- If m_{jet} is within the right mass window ($\approx m_V$) => **single jet**
- otherwise, search for **dijet pairs**

- Single jet case: consider the y scale from the k_T merging in the last step. Require p_T>300 GeV.
  Define $Y = E_T^{jet} \cdot \sqrt{y}$
  - $Y \approx O(m_V)$ if the jet comes from a boosted vector boson, and much smaller than E_T for light jets.
    Cut on 30 < Y < 100 GeV.

- Dijet case: define y from the p_T of the softest jet relative the harder.
  - Require $0.1 < \sqrt{y} < 0.45$

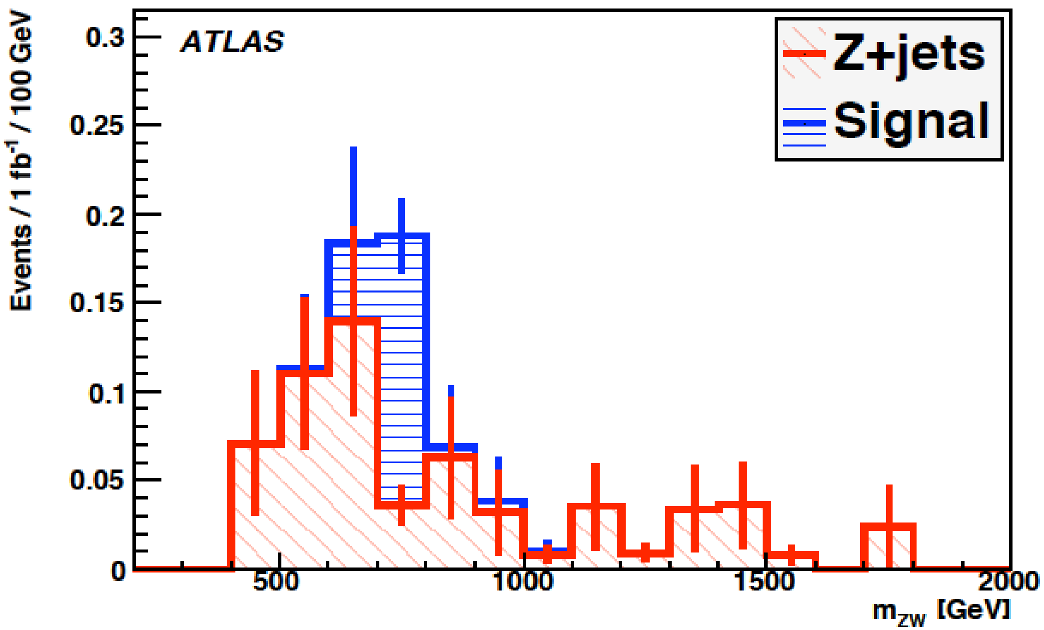
Fraction of single-jet W candidates as a function of W p_T



Vector boson scattering (3)

(CERN-OPEN-2008-020)

- Other cut considerations:
  - Select 2 forward 'tag' jets. High η jets, characteristic to VBS
  - Central jet veto. No colour exchange between the protons in VBS => suppression of QCD radiation is expected.

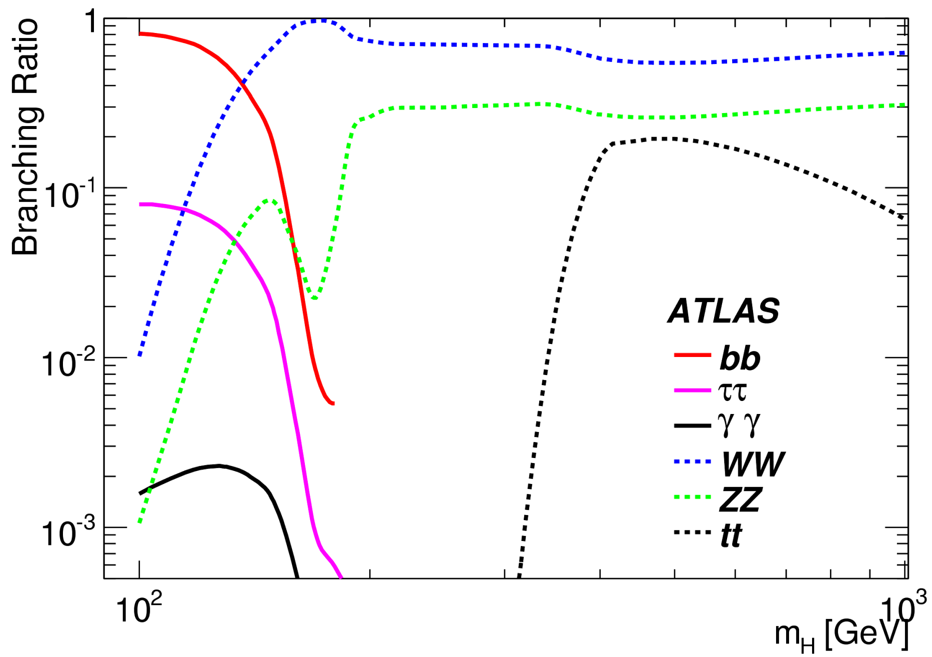


  - Top veto. ttbar production is a major background (except for Z->leptons). Top rejection through mass veto.
- Results: at 14 TeV, about 60 fb^{-1} would be required for a discovery of a semi-leptonically decaying 800 GeV WZ resonance with cross section 0.65 fb.

Higgs to *b* quarks

(ATL-PHYS-PUB-2009-088)

CERN-OPEN-2008-020



If m_H=O(10^2 GeV), $H \to b\bar{b}$ dominant

Consider $pp \to HV$, $V \to leptons$

The *b* quarks merge into one jet.

Use leptons to tag the event.

Cambridge/Aachen jet algorithm (C/A).

Similar to k_T but ordering in angles, not p_T.

The clustering stops when all jets are separated by a certain angle *R*

- Select jets with p_T>200 GeV, $|\eta|$<2.5.

  For each jet *j*,:

1) undo the last clustering step => two subjets j_1 and j_2, $m_{j1}>m_{j2}$
2) Significant mass drop? ($m_{j1} < \mu m_j$?)

   No asymmetric split? ($y > y_{cut}$?)

   } => *j* is composite

Else, start over from 1), with j_1 instead.

Parameters:

$R = 1.2$

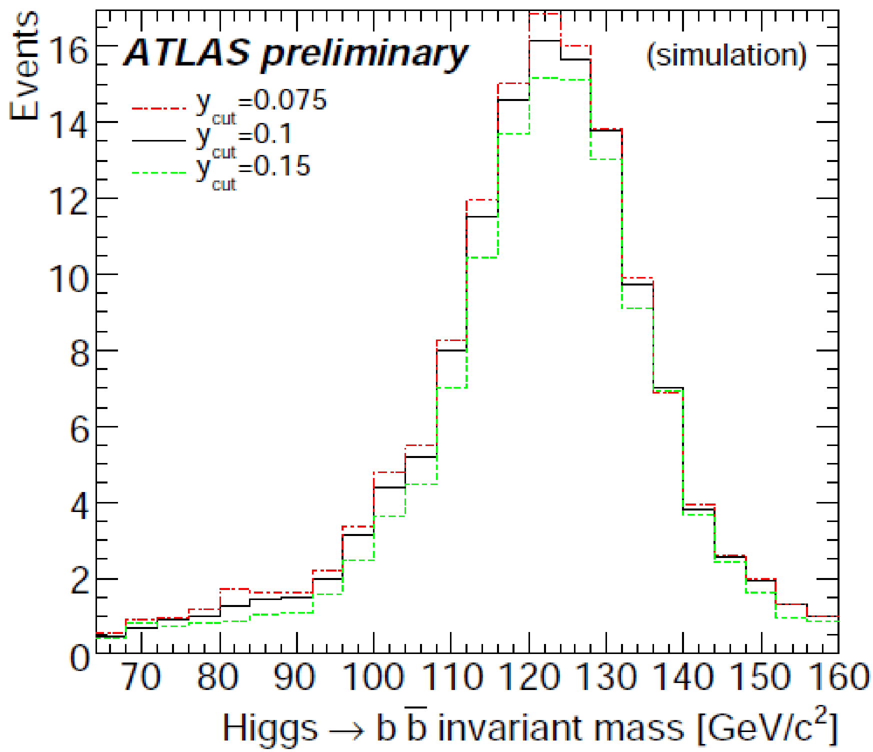
$\mu = 1/\sqrt{3}$

$y_{cut} = 0.1$

Higgs to *b* quarks (2)

(ATL-PHYS-PUB-2009-088)

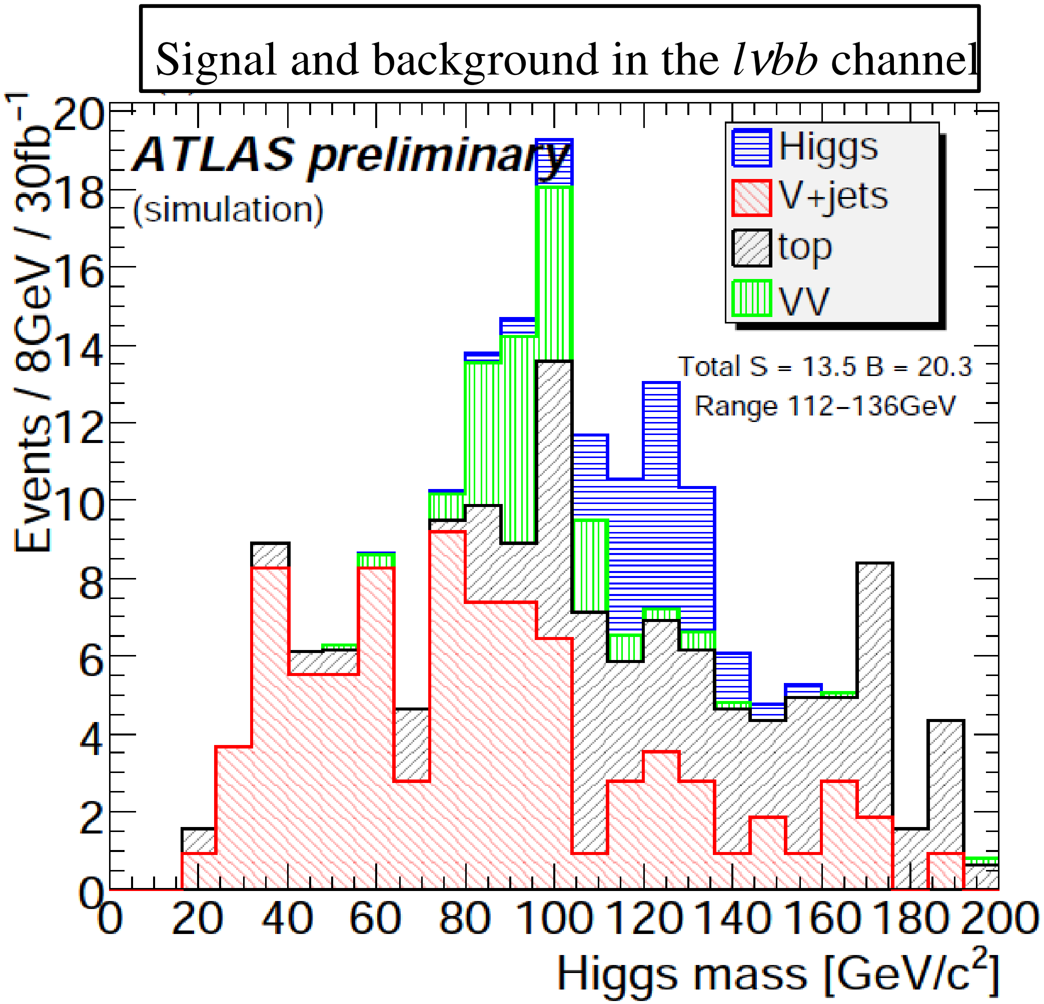
- If *j* is composite (*bb*), $\Delta R(j_1, j_2) = R_{bb}$ is the distance between the *b* quarks
- Filter the jet by rerunning C/A, now with $R_{filt} < R_{bb}$ $(R_{filt} = \min(0.3, R_{bb}/2))$
- Take the hardest three subjets
  j is a Higgs candidate
  if 2 hardest subjets
  are *b*–tagged
- Require $p_T^{\text{H cand}} > 200$ GeV (after filtering)



Higgs to *b* quarks (3)

(ATL-PHYS-PUB-2009-088)

- Choose events with leptonic *V:*
  - $W \rightarrow l+\nu$ (**$l\nu bb$ channel**).
    $E_T^{miss} > 30$ GeV,
    e or μ $p_T > 30$ GeV, $p_T^{l+\nu} > p_T^{min}$
  - $Z \rightarrow ll$ (**$ll bb$ channel**).
    ee or $\mu\mu$ pair,
    $80 < m_{ll} < 100$ GeV, $p_T^{ll} > p_T^{min}$
  - $Z \rightarrow \nu\nu$, $W \rightarrow l+\nu$ with lost l
    (**$\nu\nu bb$ channel**).
    $E_T^{miss} > p_T^{min}$
- Combine channels



Result: $S/\sqrt{B}=3.7$

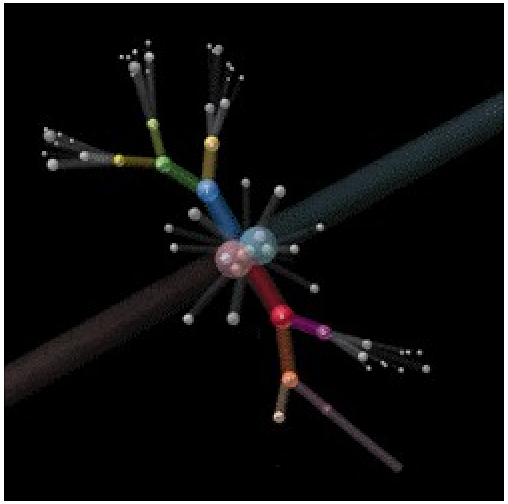
when combining channels for $\mathscr{L}=30$ fb^{-1}, $\sqrt{s}$ = 14 TeV
(LO only, no pile-up effects considered)

Top resonances in the lepton+jets channel

(ATL-PHYS-PUB-2009-081)

Reconstruction of heavy top pair resonances in the semileptonic channel, when standard top reconstruction fails

Image: Fermilab



Z' resonance, M=2, 3 TeV

SM-like, narrow, spin 1, colour singlet

- Leptonic top reconstruction
  - merged lepton / jet from b quark
- Hadronic top reconstruction
  - a jet with substructure

Selection by cutting on variables that explore these properties.

Top resonances in the lepton+jets channel (2)

(ATL-PHYS-PUB-2009-081)

Leptonic top

k_T jet algorithm, $R = 0.6$

A hard jet within a cone 0.6 centered on the lepton

l: μ, e

b: b-jet without lepton (no b-tagging)

j: b-jet with lepton inside

Variables

$$x_l = 1 - m_b^2 / m_{(b+l)}^2$$

$$y_l = p_{l\perp b} \times \Delta R(l, b)$$

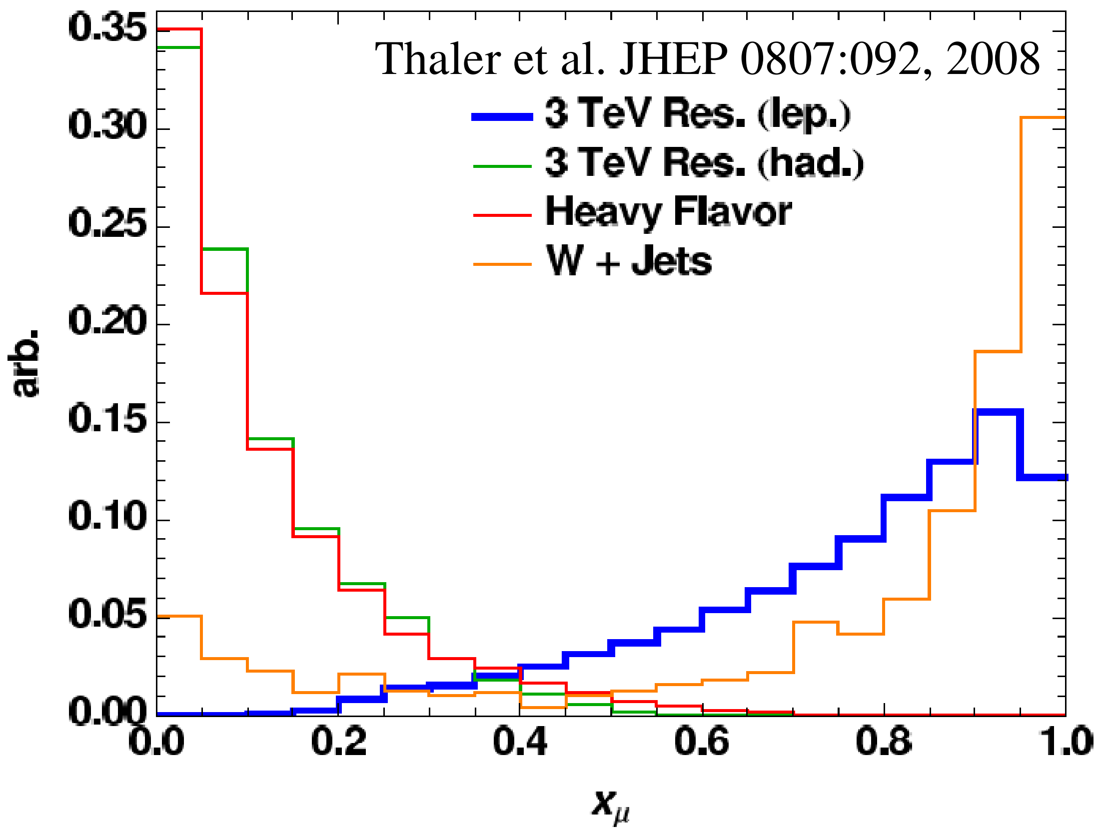
For electrons:

$$y_e' = p_{e\perp j} \times \Delta R(e, j)$$

Cuts

$$y_l > (-40 x_l + 20)\ \text{GeV}$$

$$y_e' > 1\ \text{(electrons only)}$$



Top resonances in the lepton+jets channel (3)

(ATL-PHYS-PUB-2009-081)

Hadronic top

k_T jet algorithm, R =0.6.

Search for a jet with substructure

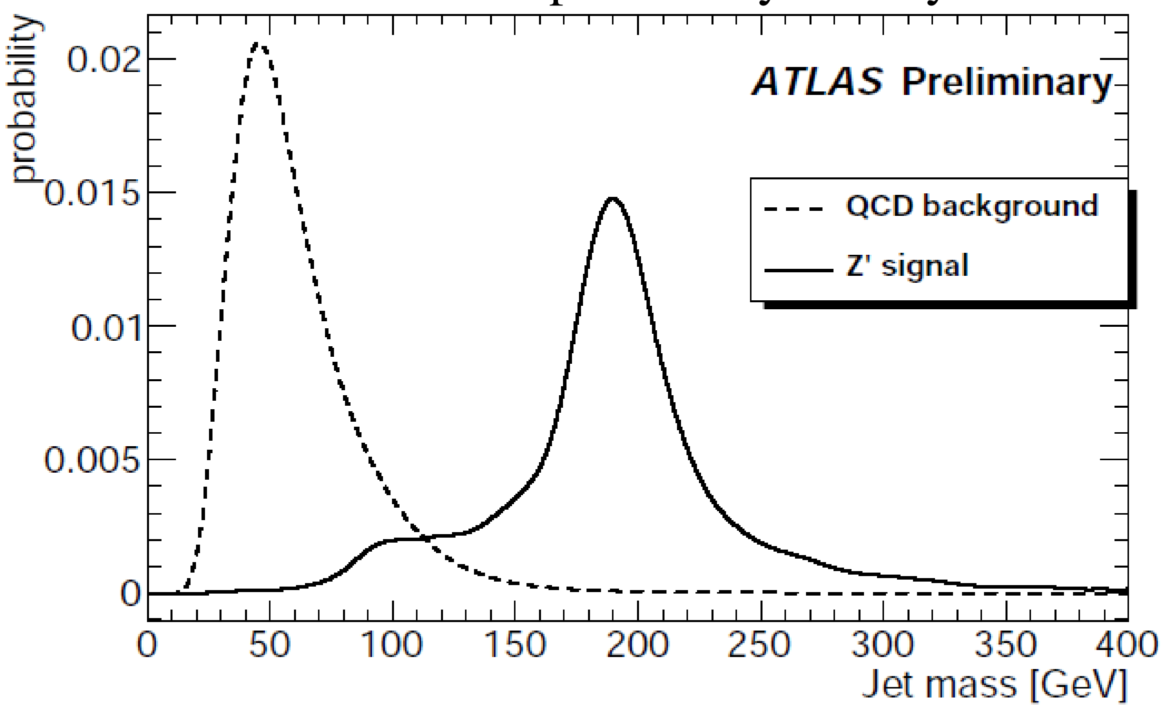
Variables

Jet mass – the mass of the hadronic top jet

k_T splitting scales into 2, 3 and 4 jets

Cut on a likelihood ratio (S/B) from pdf's of these variables.

Jet mass probability density function



Result

in the absence of a signal, for $\sqrt{s}$=14 TeV and 1 fb^{-1} of data, the limits on a Z' resonance could be set to

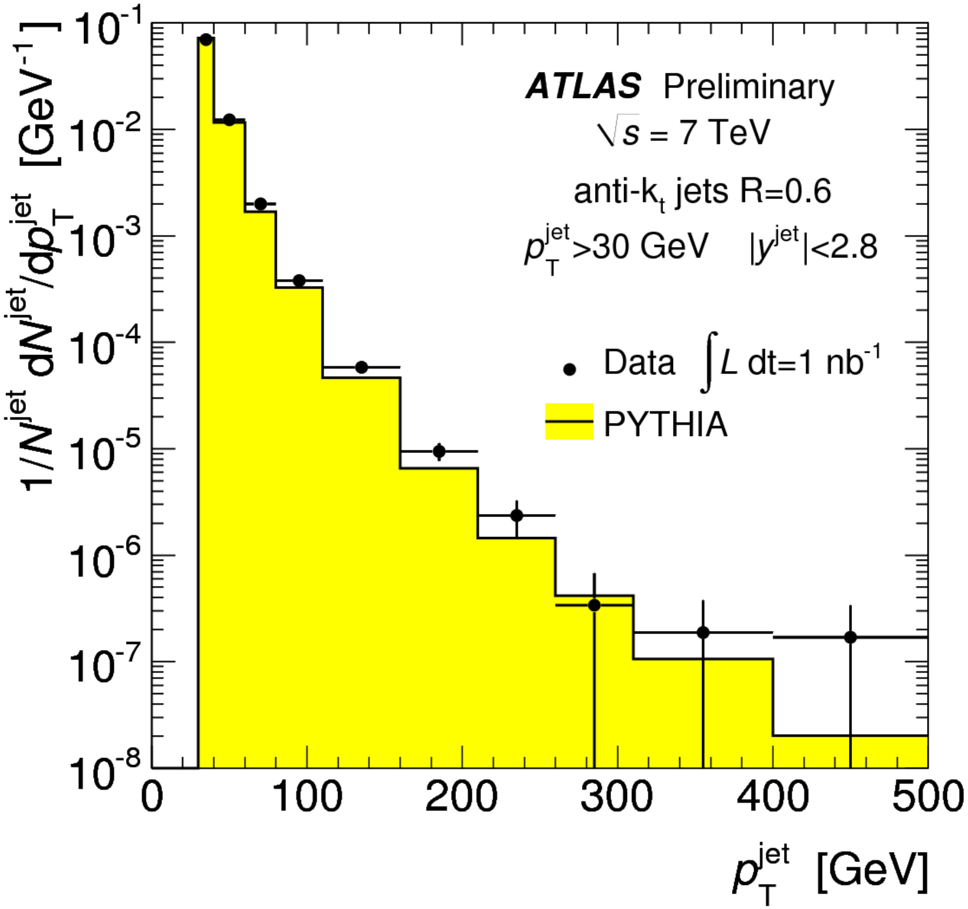
0.55 pb (2 TeV)

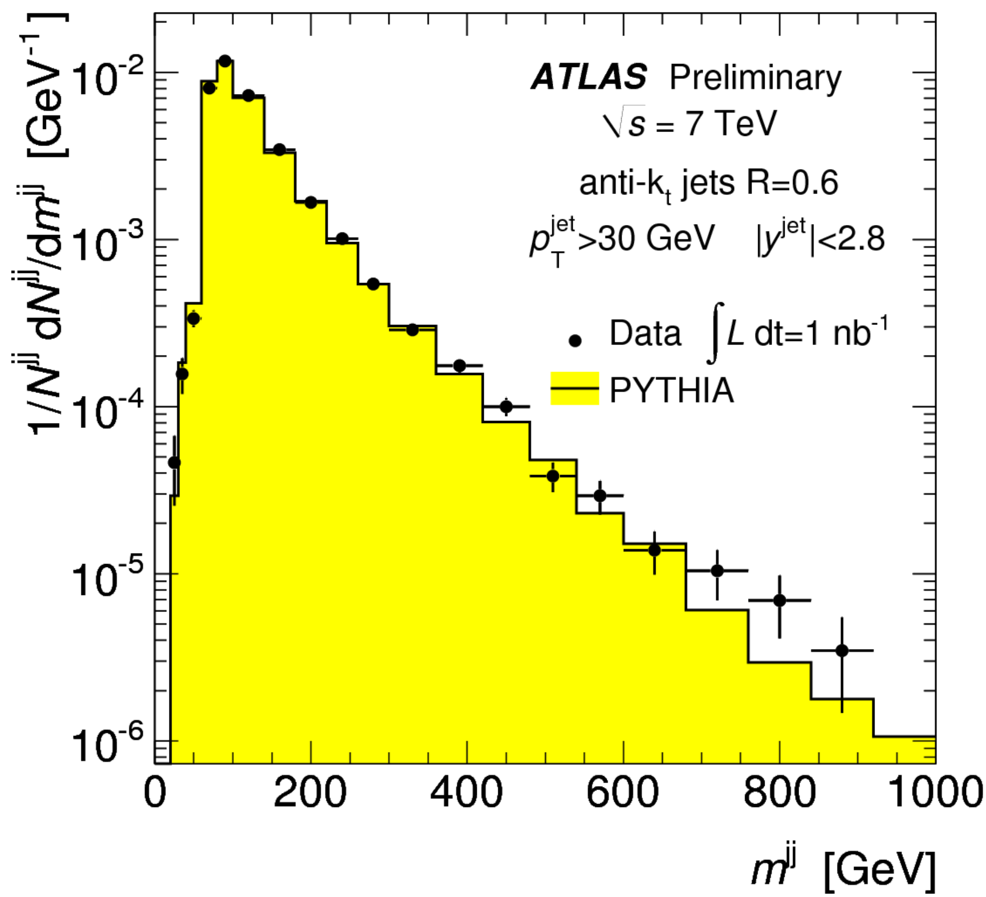
0.16 pb (3 TeV)

First high p_T ATLAS data

(ATLAS-CONF-2010-043)

- High p_T jets have been observed
- First investigation of dijet mass spectrum





From simulation to a boosted data object

- Jet substructure studies
  - Ongoing in the SM jet group
  - Each analysis group must of course make sure their favourite variables are reliable
- Higgs to *b* quarks
  - W/Z+jets studies feasible with first year data
- Studies needed to be done
  - The leptonic top variables: MC and data comparison

Conclusions and outlook

- Several detailed MC studies of boosted objects exist in ATLAS
  - Hadronic:
    Baryon number violating neutralino decays
    Vector boson scattering
    H ->bb
    hadronic top
  - Leptonic boosted top decay
- Now time for data, and validation of the MC techniques
  - First high p_T jet observations

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